BRL-TR 3210

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TECHNICAL REPORT BRL-TR-3210

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FINITE ELEMENT ANALYSES OF NONPERFORATING BALLISTIC IMPACTS USING HYDRO-CODE GENERATED LOADING HISTORIES

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FEBRUARY 1991

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
February 1991

3. REPORT TYPE AND DATES COVERED
FINAL, JAN 90 - JUN 90

4. TITLE AND SUBTITLE
FINITE ELEMENT ANALYSES OF NONPERFORATING BALLISTIC IMPACTS USING HYDRO-CODE GENERATED LOADING HISTORIES

5. FUNDING NUMBERS
1L162618AH80

6. AUTHOR(S)
ENNIS F. QUIGLEY

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US ARMY BALLISTIC RESEARCH LABORATORY
ATTN: SLCBR-DD-T
ABERDEEN PROVING GROUND, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
BRL-TR-3210

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

By modifying the EPIC-2 hydro-code one can calculate the loading history of an impacting projectile on a target. Loading histories of 20 mm projectiles for impact velocities of 366 m/s, 1012 m/s and 1508 m/s on 914 x 914 mm rolled homogeneous armor plates were calculated with this code. These histories were used in ADINA finite element analyses of the plates. Comparisons of the measured and the calculated plate responses show that hydro-code generated loading histories can be used in finite element analyses of nonperforating ballistic impact.

14. SUBJECT TERMS
TERMINAL BALLISTICS, IMPACT SHOCK, VULNERABILITY, IMPACT LOADING HISTORIES, COMPUTER SIMULATION, EPIC-2, ADINA

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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I. INTRODUCTION

A series of nonperforating ballistic impact experiments[1] were conducted by the US Army Combat Systems Test Activity to characterize the ballistic shock environment in rolled homogeneous armor targets. Three of these experiments involved the normal impact of a 20 mm fragment simulator projectile on 914 x 914 x 38 mm plates at impact velocities of 366 m/s and 1012 m/s and on a 914 x 914 x 70 mm plate at an impact velocity of 1508 m/s. Normal displacements and radial strains were measured at various locations on the back of the plates. The EPIC-2 hydro-code[2] was used by the US Army Ballistic Research Laboratory to model these three experiments and to calculate the plate's responses to the impact of this projectile. Comparison[3] of the measured and EPIC-2 calculated responses of the plates showed that EPIC-2 could calculate the response of projectile-impacted targets.

EPIC-2 is an axisymmetric code; therefore, it is limited to axisymmetric targets and to normal impact of projectiles. If, however, the EPIC-2 code is modified to calculate the projectile loading history of the target, this loading history can be used as input for a finite element analysis of ballistic shock in normal impacted, non-axisymmetric targets. The code has been modified and loading histories[4,5] have been calculated for the previously mentioned 20 mm projectile impacts. This report describes the application of these loading histories in the ADINA[6] finite element analyses of the plates and a comparison of the ADINA calculated responses with the measured responses.

II. EPIC-2 CALCULATED LOADING HISTORIES

One of the variables calculated by the EPIC-2 code for each computational time interval is the total linear momentum of the plate. The code is modified to calculate the loading history of the projectile on the plate by calculating the time rate-of-change in the plate's total linear momentum over each computational time interval. Although the computational time interval for these impact velocities is in the order of 0.05 μs, the loading is printed out at 1.0 μs intervals.

Figure 1 shows the computed loading history of the plate for impact velocity of 366 m/s. The duration time of the loading is approximately 40 μs and the maximum peak value of the loading is 800 kN. The shape of the loading pulse shows rectangular characteristics. Figure 2 shows the computed loading history for the 1012 m/s impact velocity. The duration time of the loading is 48 μs and the maximum peak value is 3.4 MN. This loading history is more oscillatory in nature than the one shown in Figure 1, and its shape exhibits triangular characteristics. Figure 3 shows the computed loading history of the plate for the impact velocity of 1508 m/s. The loading has a duration time of 68 μs and a maximum peak value of 6.3 MN. For the first 30 μs the loading is very oscillatory with differences of up to 5 MN between maximum and minimum load values. There exists at 46 μs a negative loading, implying that the projectile is pulling the plate rather pushing against it. A more reasonable explanation can be given in terms of the dilatation wave produced by the impacting projectile. The time at which the negative loading occurs is the arrival time of the wave at the impact point after the wave's second round trip through the 70 mm thickness of the plate. Since this is a tension wave when it arrives, the plate experiences a pulling rather than a pushing. Although the lower impact velocity loading histories show some characteristic shape, this higher velocity loading history does not.

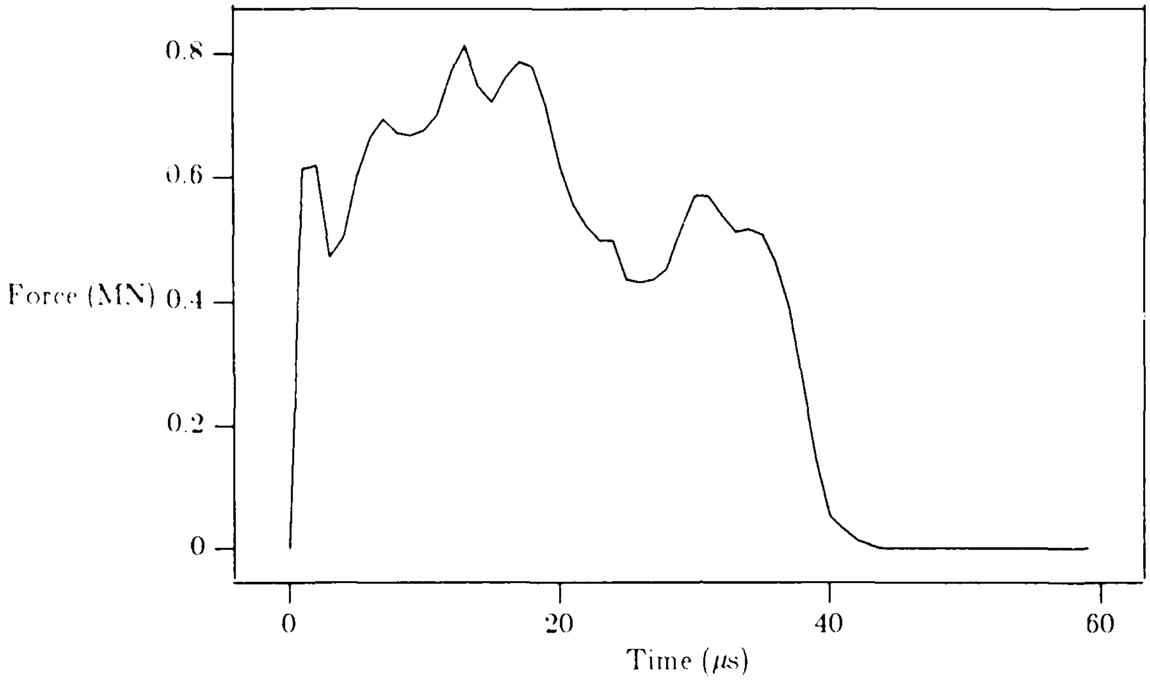

Figure 1. EPIC-2 calculated impact loading history for $v_p = 366$ m/s.

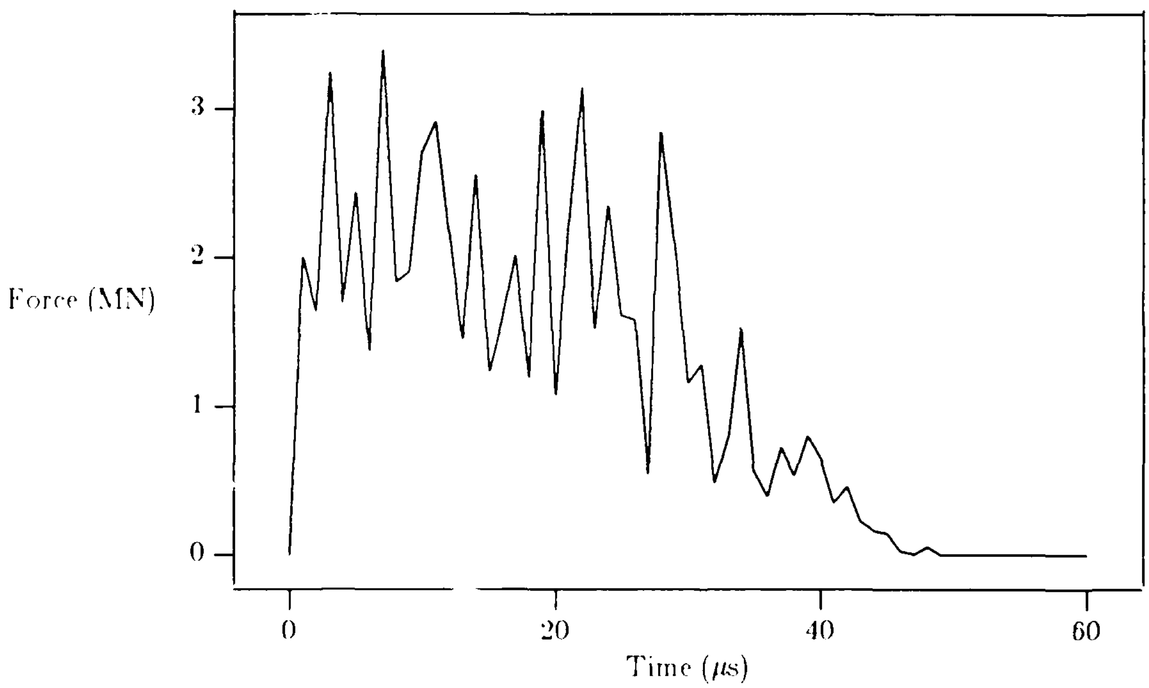

Figure 2. EPIC-2 calculated impact loading history for $v_p = 1012$ m/s.

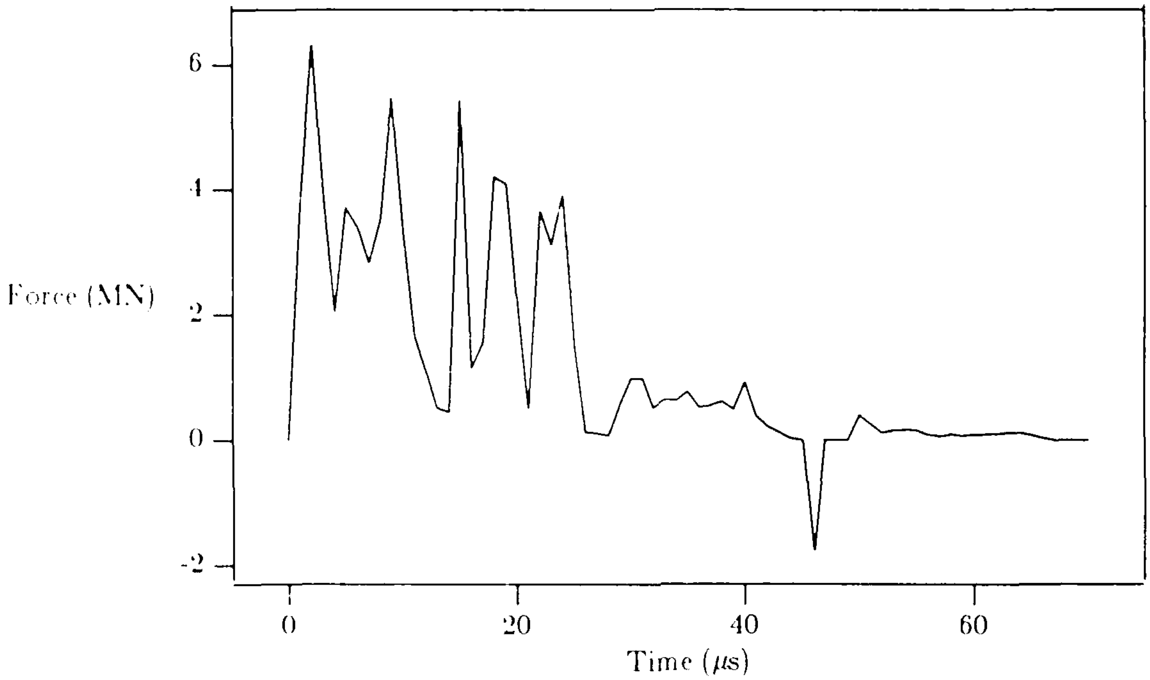

Figure 3. EPIC-2 calculated impact loading history for $v_p = 1508$ m/s.

III. ADINA CALCULATIONS

The ADINA finite element models of the plates are identical to the models used in the EPIC-2 calculations of the plates' responses[2] and the loading histories[4,5]. The square plates are modeled as a circular ones with radii of 457 mm and having free boundaries. The analyses are axisymmetric. The 38 mm thick plate model consists of 671 nodes and 1200 triangular elements. Both the horizontal and the vertical distances between the nodes are 7.62 mm. The 70 mm thick plate model consists of 1029 nodes and 1760 triangular elements. The horizontal and the vertical distances between the nodes are 7.62 mm and 8.67 mm, respectively. One third of the loading is applied to each of the top first three radial nodes. (Recovery of the 20 mm projectiles after the experiments showed that the contact surface of the projectile mushroomed from a 20 mm diameter to a 33 mm diameter.) The analyses are nonlinear material only, small deflection and small strain. The time integration scheme used is the Newmark method with a time step increment of 1 μs. The full Newton equilibrium iteration method without line search is used for the 38 mm thick plates, and the full Newton equilibrium iteration method with line search is used for the 70 mm thick plate

The material model of the plates is bilinear elastic-plastic in which Young's modulus $E =$ 145.1 GPa, Poisson's ratio $\nu = 0.275$, yield stress $\sigma_Y = 916.2$ MPa, and strain hardening modulus $E_T = 510.1$ MPa; and the density of the plate is 7876 kg/m^3. The same material properties were used in the EPIC-2 calculations of the loading histories.

IV. COMPARISON OF CALCULATED AND MEASURED RESPONSES

Figures 4 through 17 show the calculated and measured plate response histories at the 100 mm, 106 mm, 170 mm, 240 mm and 244 mm transducer locations for the first 300 μs. For times greater than 250 μs, the plate's geometry and boundary conditions do affect the plate's response, and any comparison of data is not meaningful. Zero times of the measured responses, normal displacements and radial strains, do not coincide with the time of impact and therefore do not correspond to the zero time of the calculated responses. Zero times of the measured responses are adjusted in order to compare the data, and these adjusted times are the same ones used in the comparison[2] of the EPIC-2 calculated responses with the measured responses.

Figures 4 through 8 show the responses of the 38 mm thick plate for the impact velocity of 366 m/s. Figures 9 through 13 show the responses of a similar plate for the 1012 m/s impact velocity. Figures 14 through 17 are for the 70 mm thick plate for the impact velocity of 1508 m/s. It can be seen from these figures that the agreement between the measured plate responses and the calculated responses ranges from good to excellent.

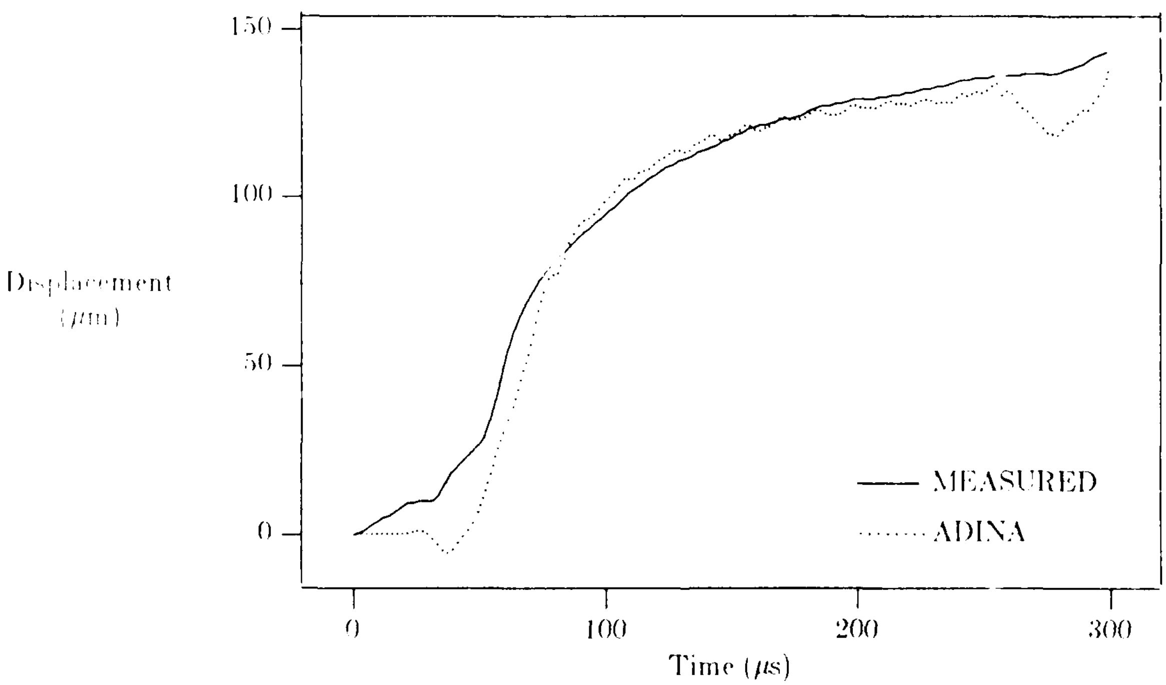

Figure 4. Normal displacement histories at 106 mm for v_p = 366 m/s.

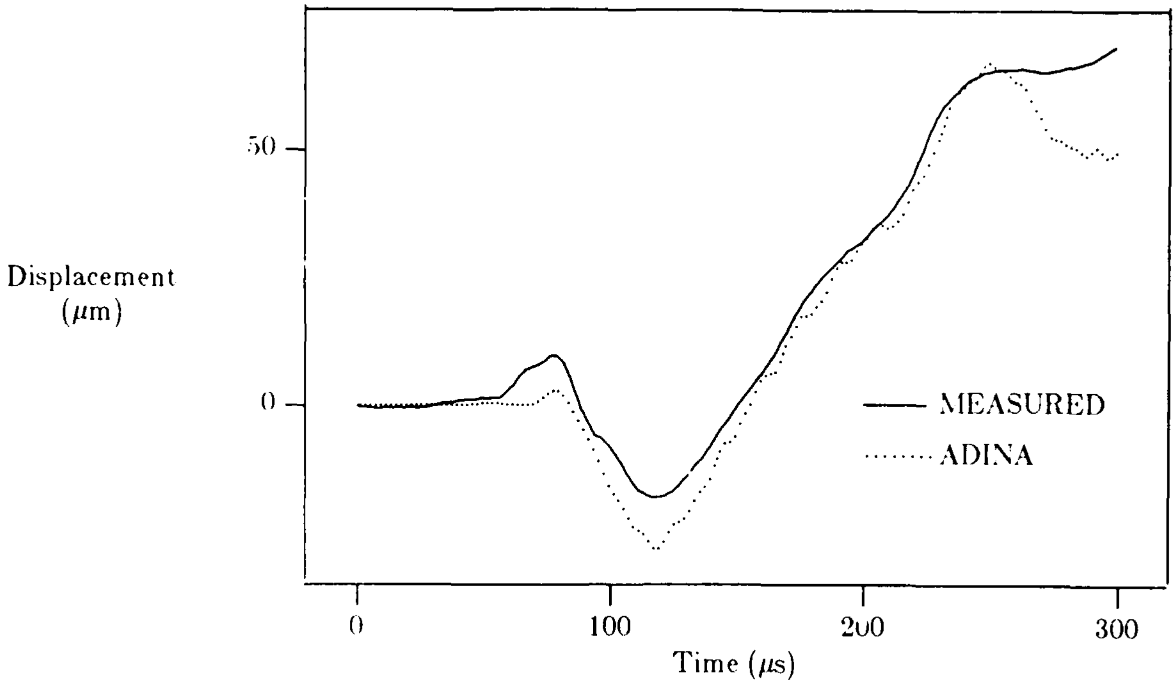

Figure 5. Normal displacement histories at 244 mm for $v_p = 366$ m/s.

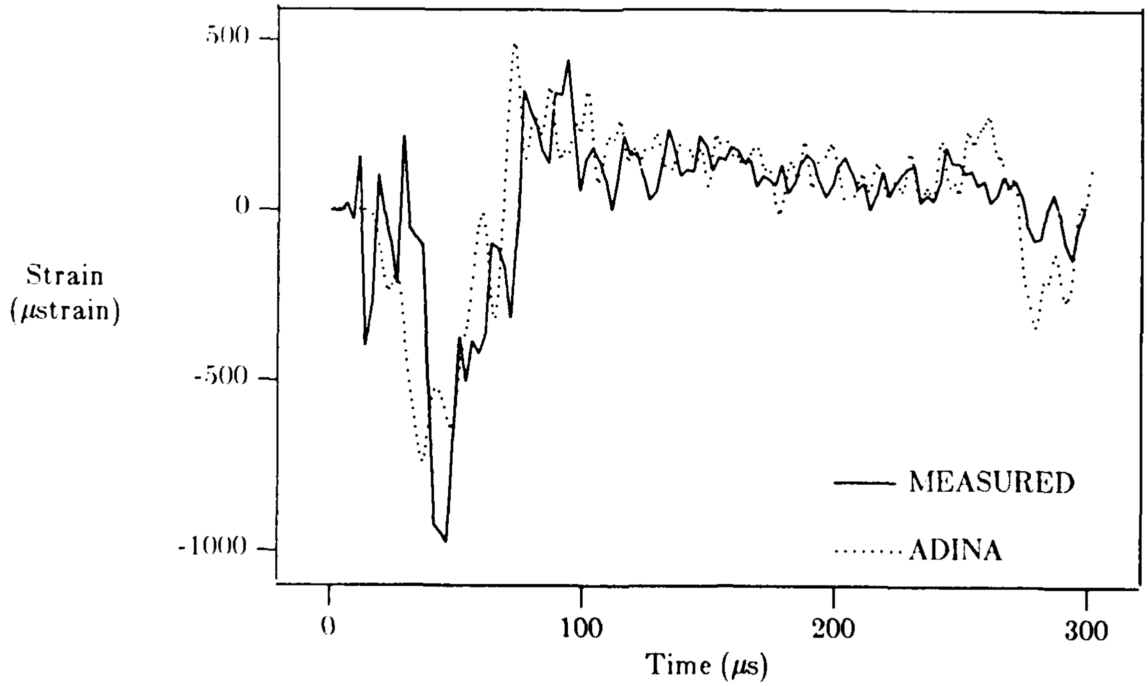

Figure 6. Radial strain histories at 100 mm for $v_p = 366$ m/s.

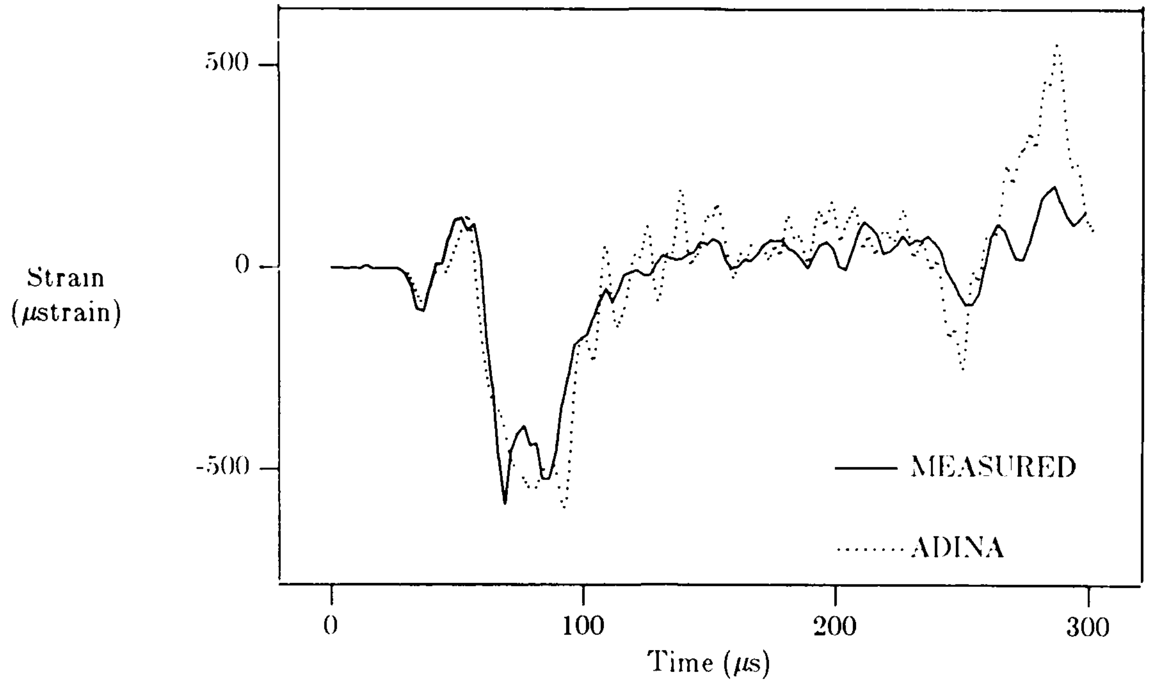

Figure 7. Radial strain histories at 170 mm for $v_p = 366$ m/s

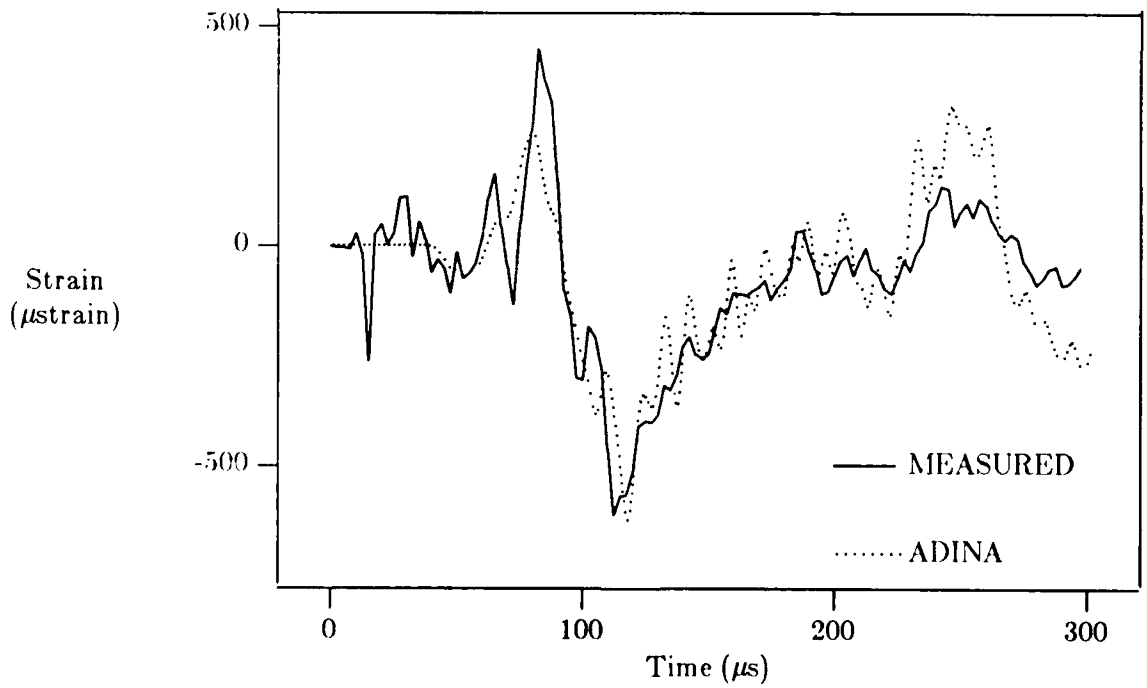

Figure 8. Radial strain histories at 240 mm for $v_p = 366$ m/s.

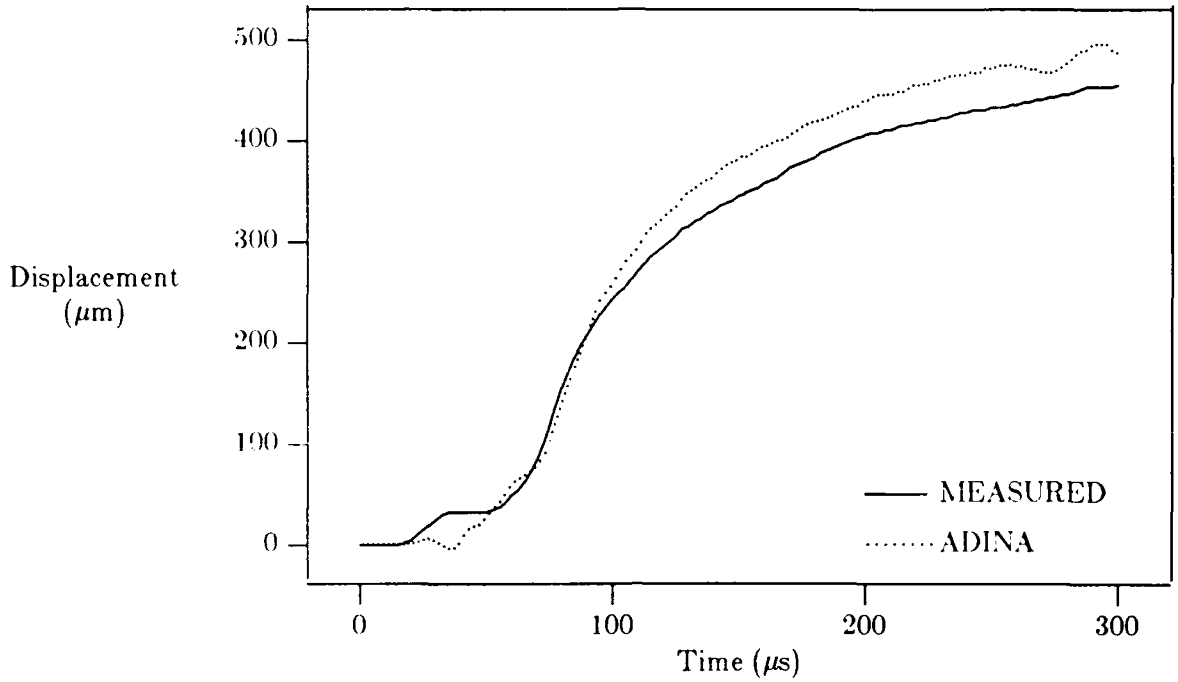

Figure 9. Normal displacement histories at 106 mm for $v_p = 1012$ m/s.

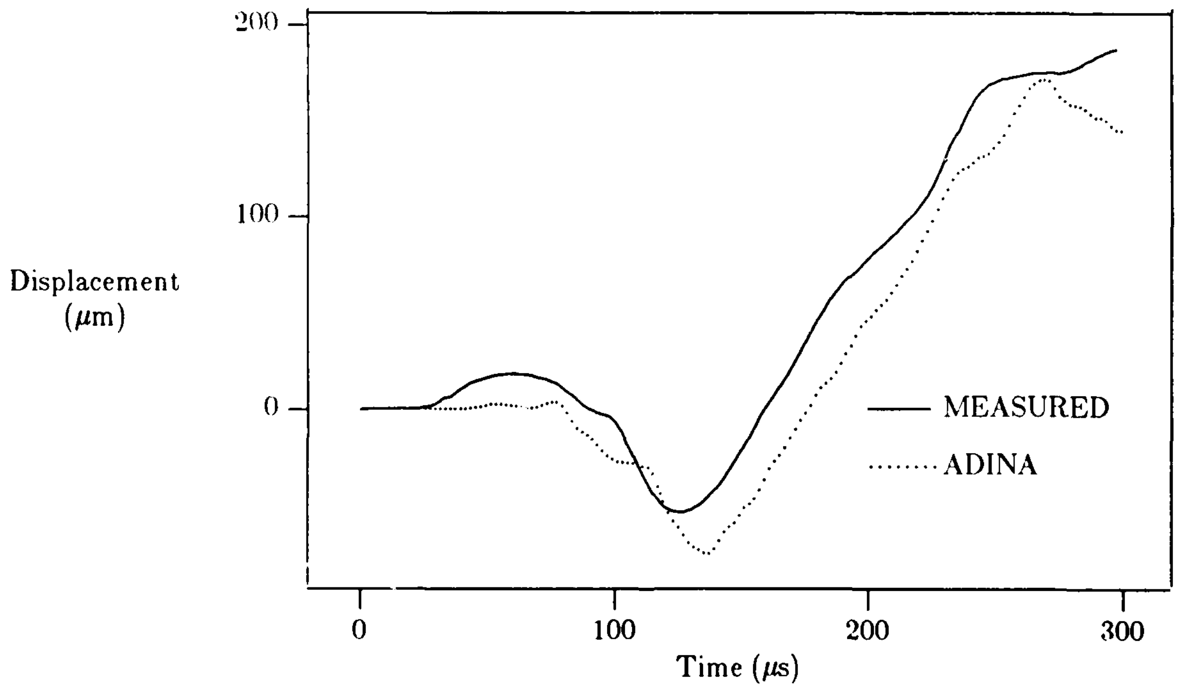

Figure 10. Normal displacement histories at 244 mm for $v_p = 1012$ m/s.

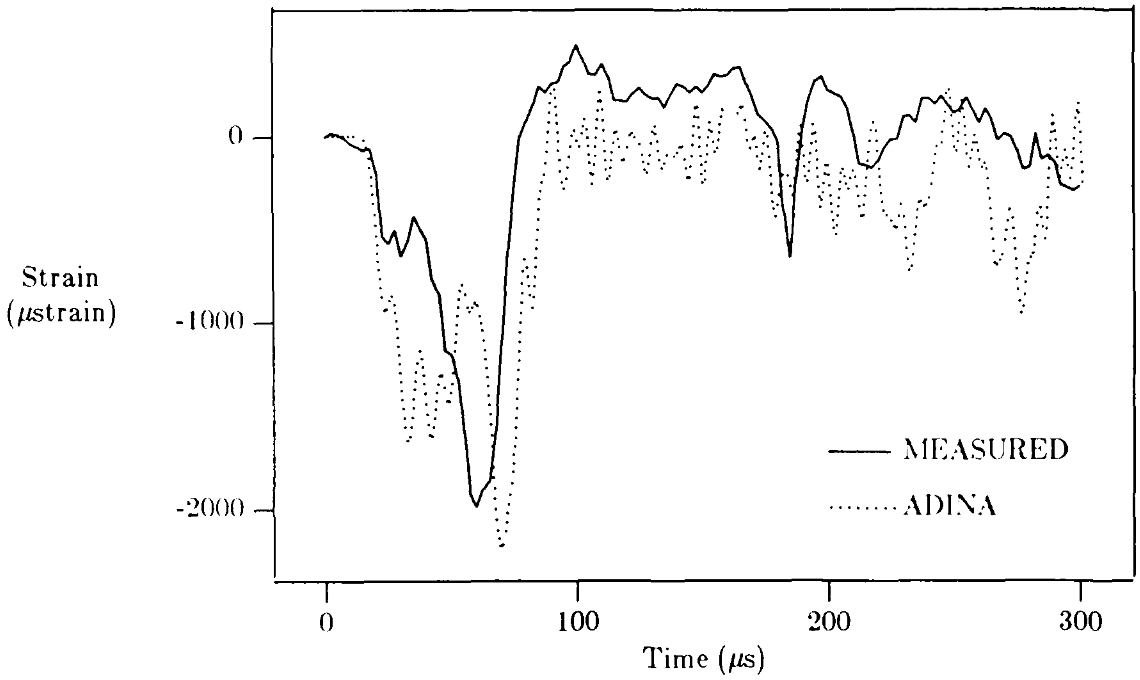

Figure 11. Radial strain histories at 100 mm for v_p = 1012 m/s.

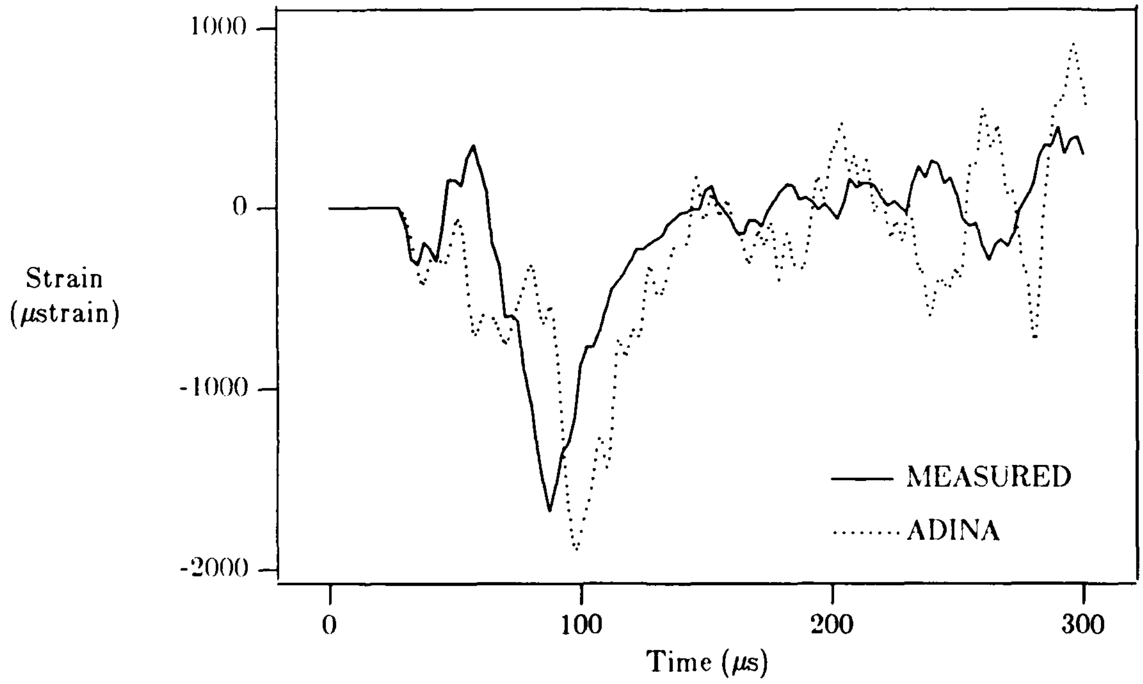

Figure 12. Radial strain histories at 170 mm for v_p = 1012 m/s.

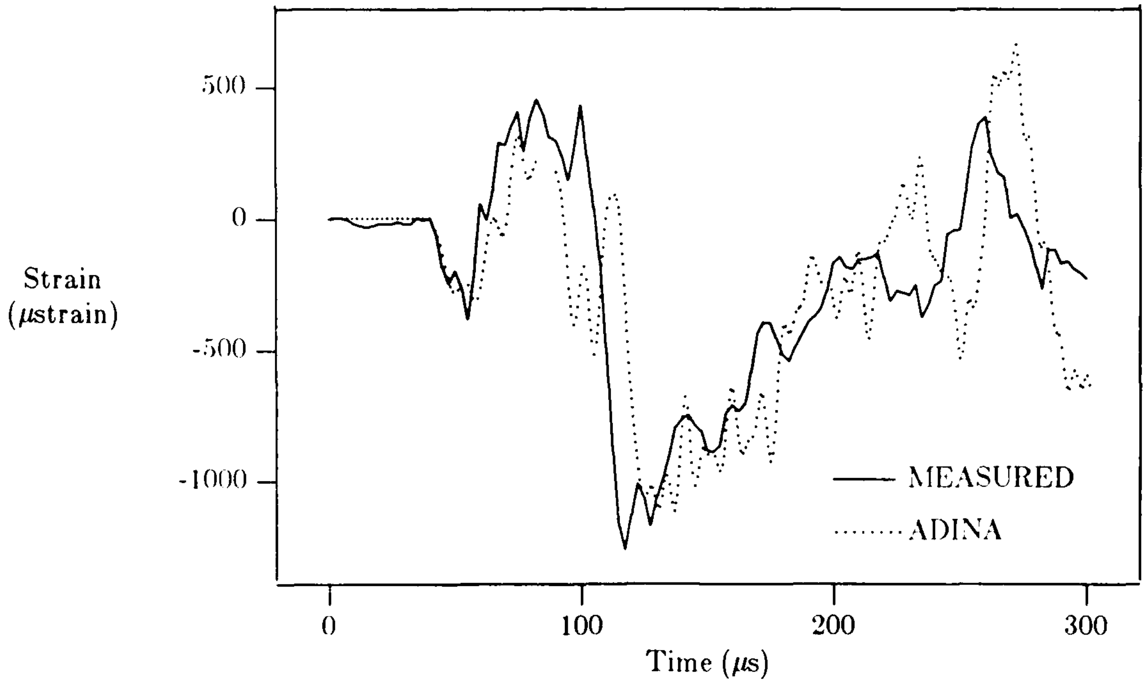

Figure 13. Radial strain histories at 240 mm for v_p = 1012 m/s.

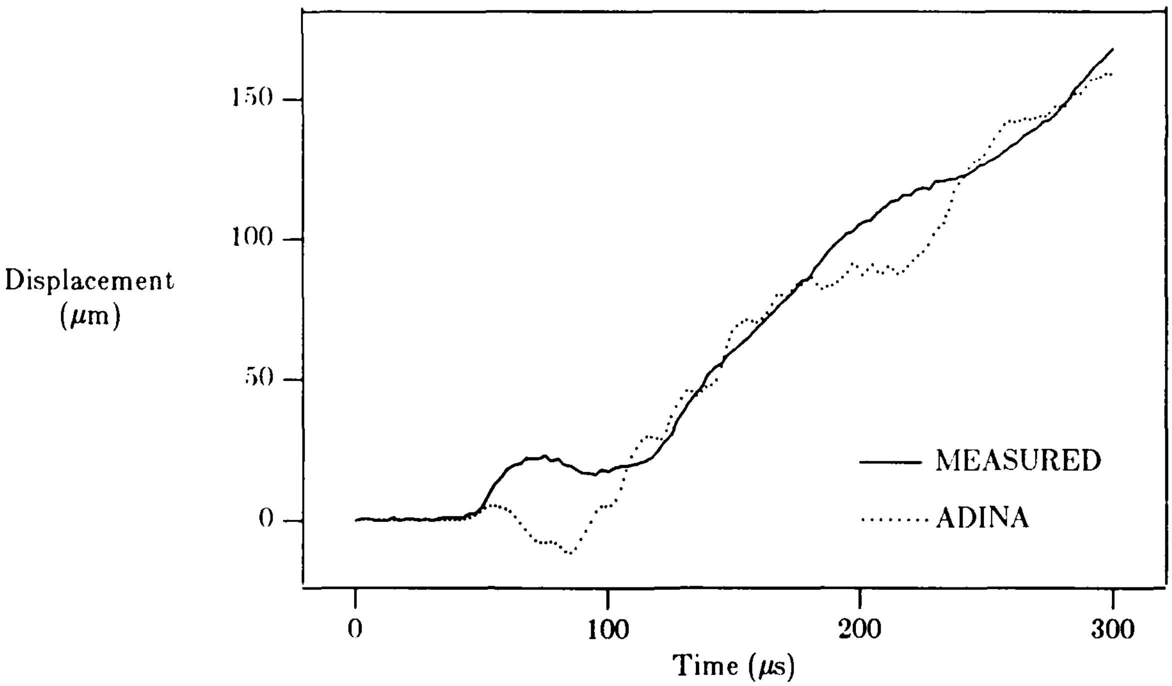

Figure 14. Normal displacement histories at 244 mm for v_p = 1508 m/s.

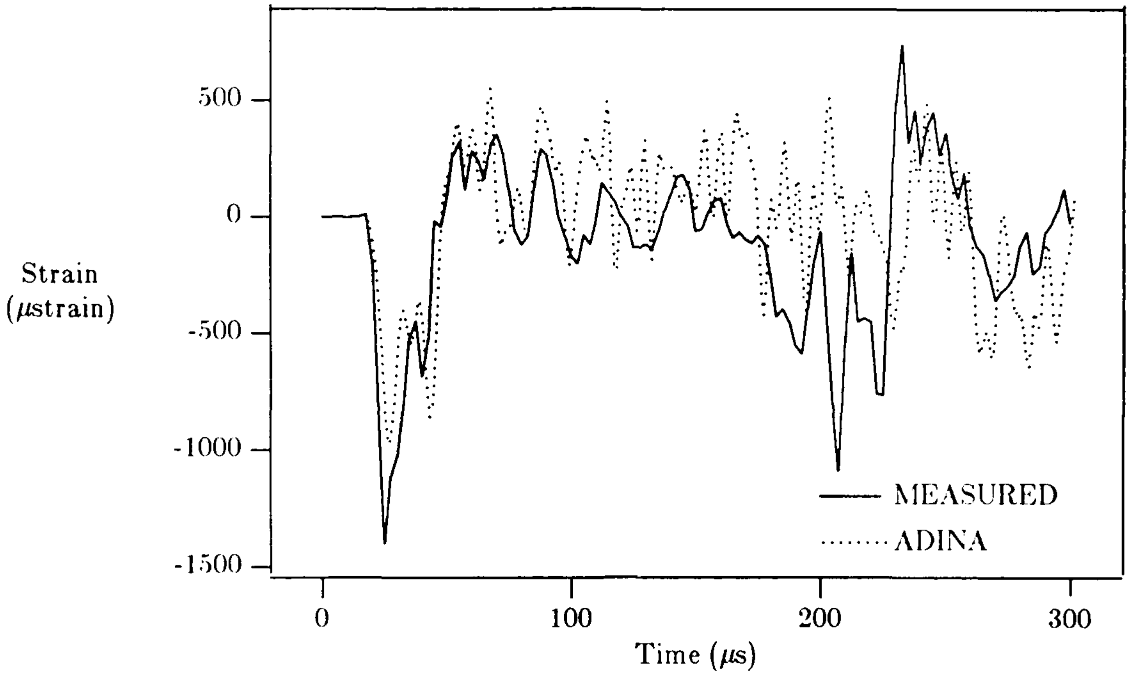

Figure 15. Radial strain histories at 100 mm for v_p = 1508 m/s.

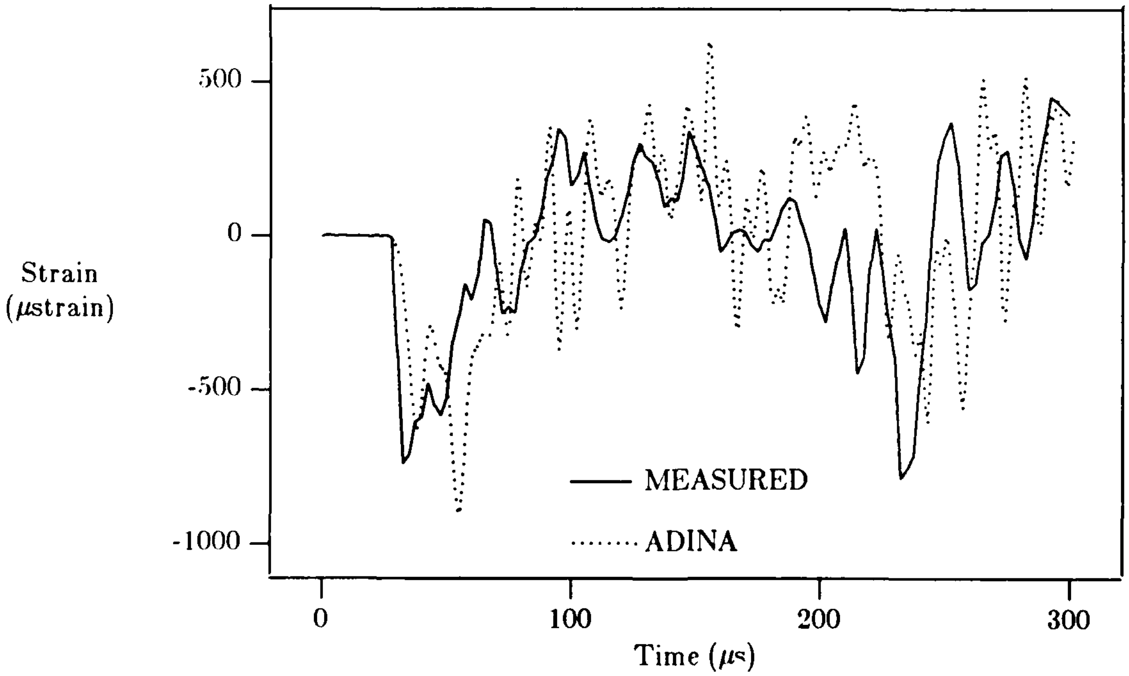

Figure 16. Radial strain histories at 170 mm for v_p = 1508 m/s.

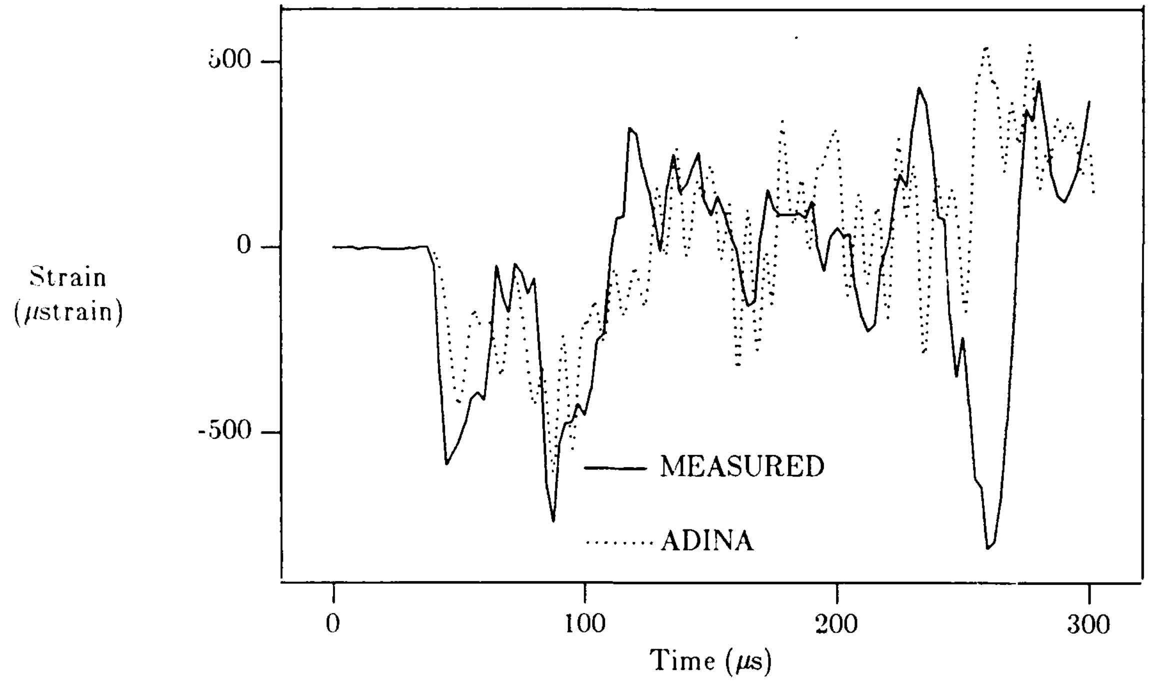

Figure 17. Radial strain histories at 240 mm for v_p = 1508 m/s.

V. SUMMARY AND CONCLUSIONS

EPIC-2 hydro-code calculated loading histories of rolled homogeneous armor plates from impacting 20 mm projectiles have been used in finite element analyses of the plates' responses to these impacts. The projectile impacts were normal to the plate surface and nonperforating. During the computation of the loading histories, the projectile material was allowed to fail and erode whereas the plate material was not. Comparison of the measured and the finite element calculated responses of the plates show that these calculated loading histories when used in finite element analyses of the plates' responses give good to excellent results for this particular type of impact.

Non-normal impact, kinetic energy rod impact and shaped charge warhead impact are of greater importance. The latter is of special interest in that it involves both high explosive blast loading and shaped charge jet loading. Whether or not hydro-codes can provide loading histories for these types of impact for use in finite element analyses of ballistic impact is a question still to be answered.

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